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Evaluating elevated convection with the downdraft convective inhibition

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Abstract

A method for evaluating the penetration of a stable layer by an elevated convective downdraft is discussed. Some controversy exists on the community's ability to define truly elevated convection from surface-based convection. By comparing the downdraft convective inhibition (DCIN) to the downdraft convective available potential energy (DCAPE), we determine that downdraft penetration potential is progressively enabled as the DCIN is progressively smaller than the DCAPE; inversely as DCIN increases over DCAPE, so does the likelihood of purely elevated convection. Serial vertical soundings and accompanying analyses are provided to support this finding.

Keywords: **elevated convection; downdraft convective inhibition**

1. Introduction

Elevated convection has long been known as a producer of both significant convective rainfall (Rochette and Moore, 1996) and snowfall (Moore *et al.*, 1998) in the United States as well as Europe (Browning *et al.*, 2012). The unique combination of the shallow thermal boundary and low-level jet (Trier and Parsons, 1993; Augustine and Caracena, 1994), and favorable upper-level flow structure (Moore *et al.*, 2003) often provide for prolonged moisture inflow and a wind profile suitable for slow-moving and/or training echoes. In addition, recent work for the central United States has also shown that elevated convection produces more precipitation as well as more positive lightning flashes than geographically and seasonally comparable surface-based convection (Kastman *et al.*, 2015).

For some time, there have been valid concerns about how to assess whether deep moist convection is purely elevated (Corfidi *et al.*, 2008). Recent modeling (Parker, 2008; Nowotarski *et al.*, 2011; Billings and Parker, 2012; Schumacher, 2015) and observational studies (Marsham *et al.*, 2011; Billings and Parker, 2012) suggest that when some amount of near-surface (boundary-layer-based) convective available potential energy (CAPE) is available, despite much higher amounts of elevated or most unstable CAPE, there is often still some degree of boundary-layer air contributing to the convection. Based on these studies, it appears safe to conclude that if some amount of near-surface CAPE is available, even with significant convective inhibition (CIN) in the profile (Parker, 2008; Schumacher, 2015), then the convection is likely surface-based to some degree. That is, not to say that convection might not be dominated by elevated convection, which did seem to be the case in the parcel tracer results of Nowotarski *et al.* (2011) and Schumacher (2015). But, given that elevated convection is defined by not having any surface parcel influence (Colman, 1990a, 1990b; Corfidi *et al.*, 2008), it seems only safe to consider convection elevated when no surface-based CAPE is present (Nowotarski *et al.*, 2011). Certainly, convection can be elevated even when near-surface parcels have positive CAPE, as suggested by Nowotarski *et al.* (2011) in the case that had 1171 J kg^{-1} of surface-based CAPE but no surface parcels were ingested in the tracer results, though this seems to be the exception. Thus, improved methods of assessing whether convection is elevated are needed in situations where there are appreciable amounts of CIN due to a low-level inversion, yet some degree of near-surface CAPE may remain.

This work examines the downdraft convective available potential energy (DCAPE), and compares it to the sounding's downdraft convective inhibition (DCIN). In much, the same way that one might assess a thunderstorm updraft and the negative area above the equilibrium level to estimate the height of the overshooting top of a cumulonimbus (Djurić, 1994, cf. Fig. L-1), one may assess a thunderstorm downdraft and compare its DCAPE to its DCIN. We propose that, as the DCIN becomes progressively larger than the DCAPE, it is progressively more difficult for a downdraft to penetrate down toward the surface; the condition where DCIN > DCAPE further confines near-surface parcels to the subinversion layer.

2. Data and methods

Our work focuses on determining means by which surface-based parcels may become incorporated into the larger convective circulation above. As such, we examine the DCAPE, and how it can represent the potential for a downdraft to penetrate the near-surface stable layer. The DCAPE posed for elevated convection is similar to that in Gilmore and Wicker (1998):

$$DCAPE = g\int_{Z_{nb}}^{Z_n} \frac{\theta_v(z) - \theta_v'(z)}{\theta_v(z)} dz \quad (1)$$

where, $\theta_v(z)$ and $\theta_v{}'(z)$ are the virtual potential temperatures of the environment and saturated downdraft parcels, respectively (following Doswell and Rasmussen, 1994); Z_n is the height from which the saturated parcel begins its descent and Z_{nb} is the level of neutral buoyancy. The lower bound, Z_{nb}, is of course the significant change, as we consider here the presence of near-surface layers beneath an inversion that can act to slow/stop a downdraft's descent. DCAPE represents the negative buoyancy of a parcel within the saturated downdraft and has become well established in the meteorological community in the last ~20 years. However, this value has commonly been used in conjunction with studies of surface-based convection, and so it is presumed that the downdraft will travel all the way to the surface, unabated.

With elevated convection, this is not necessarily the case. Indeed, a negative area on a thermodynamic diagram can be represented for the downrushing parcel that becomes warmer than its environment in the near-surface stable layer; we label this quantity the DCIN, and represent it mathematically as:

$$DCIN = g\int_{Z_{sfc}}^{Z_{nb}} \frac{\theta_v(z) - \theta_v'(z)}{\theta_v(z)} dz \quad (2)$$

where, the values are identical to those for DCAPE, except for the limits of integration, which are now the level of neutral buoyancy Z_{nb} above, and the surface of the earth, Z_{sfc}. Graphical examples of DCIN are provided in the ensuing section, using new functionality in the *RAOB* software. DCAPE and DCIN values are based upon parcels originating from the coldest wet bulb temperature in the lowest 6 km.

Data for these cases came from rawinsonde flights conducted during the summers of 2014 and 2015 as a part of the North American study of elevated convection known as the Program for Research on Elevated Convection with Intense Precipitation (PRECIP, http://weather.missouri.edu/PRECIP/). We also revisit five soundings from a previous study on elevated convection with severe wind reports (Horgan *et al.*, 2007) for comparison purposes.

3. Analysis

Consecutive soundings are examined for warm season dates in 2014 and 2015 for locations on the North American interior. Both cases of elevated convection occurred in the central United States, over the state of MO specifically.

3.1. Case 1: 2 April 2014

The first case to be examined occurred on 2 April 2014 over Clinton, MO, USA, north of a slow-moving warm frontal boundary (Figure 1). Sounding balloons were

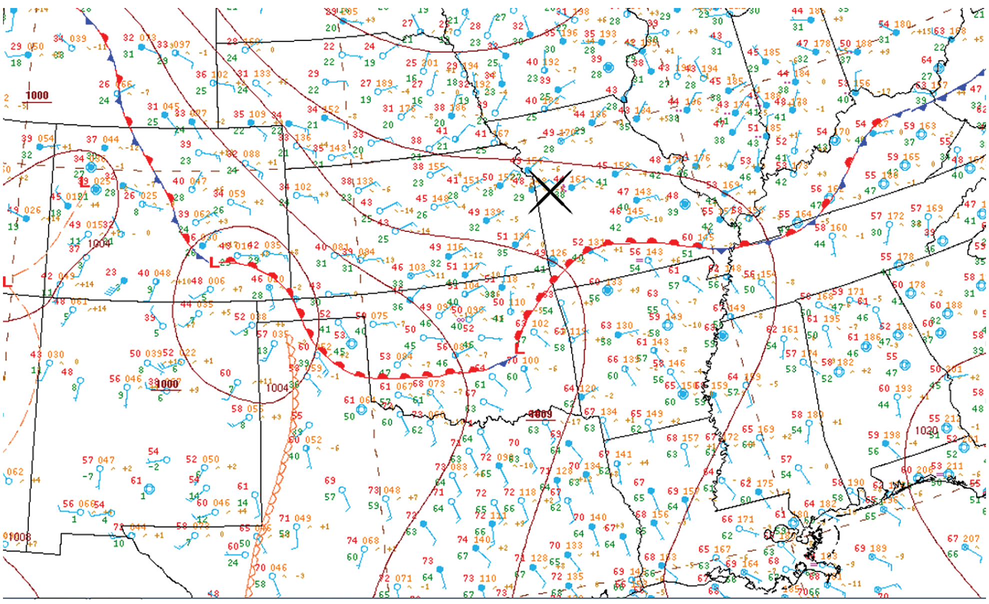

Figure 1. Standard surface analysis for the central United States valid at 0600 UTC 2 April 2014 from the United States Weather Service Weather Prediction Center. Bold 'X' marks the location of Clinton, MO.

released every 2 h from 0000 UTC to 1200 UTC 2 April 2014. Here, we focus on the flights from 0534 UTC (Figure 2(a)), 0753 UTC (Figure 2(b)) and 0937 UTC (Figure 2(c)).

Convection had just begun in the area by the time of the 0534 UTC launch (Figure 2(a)), and the flight terminated early at ∼571 hPa. Yet this depth was sufficient to provide an estimate of the DCAPE [the upper, darker purple area in Figure 2(a); 160 J kg^{-1}] as well as the comparable DCIN [the lower, lighter purple area in Figure 2(a); 163 J kg^{-1}]. Surface winds are examined for gusts above background for both cases (Figure 3). A background easterly flow of ∼8 knots was noted at this time, with no gustiness noted at the launch site, or the nearby (∼6.4 km east of the launch site) automated surface observing station (ASOS) in Clinton, MO [KGLY; Figure 3(a)].

The ensuing flight at 0753 UTC (Figure 2(b)) featured a dramatic increase in the DCAPE (314 J kg^{-1}) along with a diminished DCIN (119 J kg^{-1}). A second wave of convection had just passed by the sounding launch site, and nearly directly over the KGLY ASOS site (Figure 3(a)). Gusts of 18–20 knots occurred between 0655 UTC and 0755 UTC, beginning immediately after a reflectivity core of 53 dBz (observed from the nearby National Weather Service radar at Pleasant Hill, MO; centerline of lowest tilt ∼880 m above ground level) passed over KGLY. Given the excess of DCAPE over DCIN, and the observed changes at the surface, penetration of the elevated convective downdraft to the surface appears to have occurred.

The final flight examined was launched at 0937 UTC (Figure 2(c)) revealing a DCAPE that had diminished some to 266 J kg^{-1}, and the DCIN had grown to 125 J kg^{-1}. Even so, the balloon was launched in the absence of precipitation, or nearby strong (>40 dBz) reflectivity cores on the radar. Surface-observed gustiness had abated (Figure 3(a)).

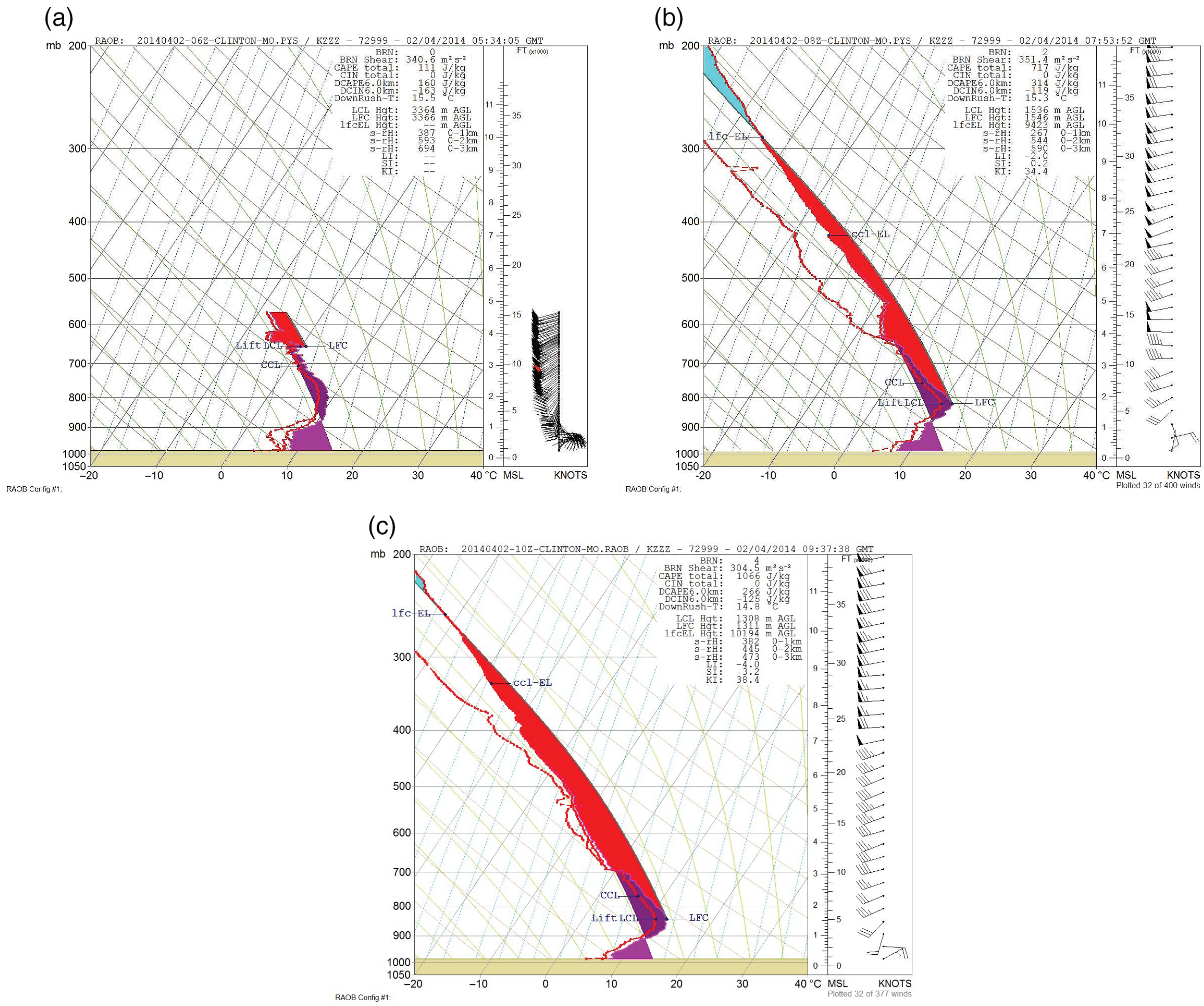

Figure 2. Sounding analyses from Clinton, MO, flown on 2 April 2014, and launched at (a) 0534 UTC, (b) 0753 UTC and (c) 0937 UTC. The right and left red traces represent the temperature and dew point temperatures, respectively; the purple trace to the right of the temperature trace is the virtual temperature. The convective available potential energy (CAPE) for the most unstable parcel is shaded in red, convective inhibition (CIN), if any, for that same parcel is shaded in light blue, DCAPE for the coldest wet bulb temperature in the lowest 6 km is shaded in dark purple, and the DCIN for that same parcel is shaded in a lighter purple; each of these values is calculated with the virtual temperature correction applied.

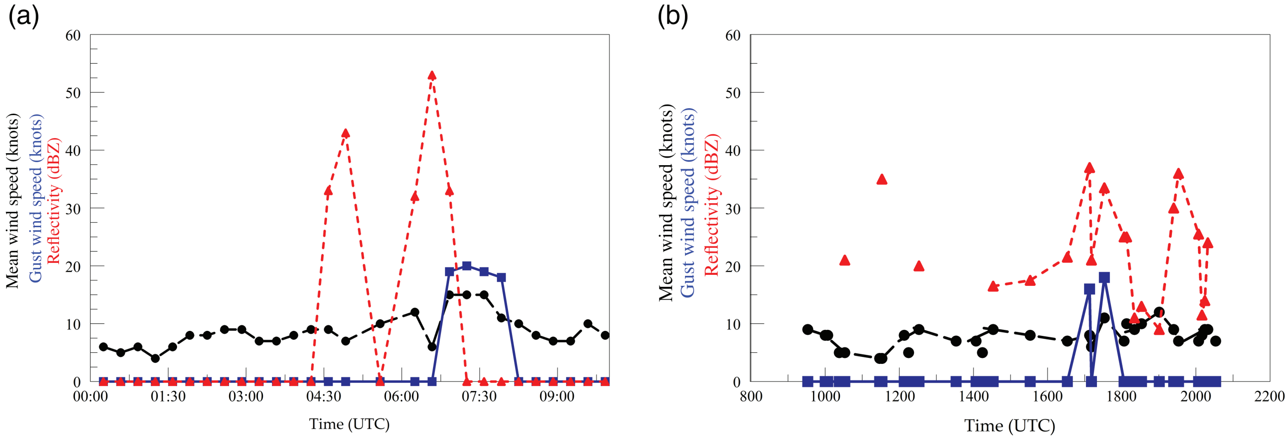

Figure 3. Plots of time (abscissa) versus wind speed (knots; ordinate) and reflectivity (dBz; ordinate) for (a) the location of the Clinton, MO, airport (KGLY) on 2 April 2014 and (b) the location of the Jefferson City, MO, airport (KJEF) on 8 July 2015. Wind speeds are represented by black filled circles (joined by a line of long dashes), wind gusts by blue filled squares (joined by a solid line), and reflectivity values (from a) Pleasant Hill, MO, National Weather Service radar; and (b) the University of Missouri radar) by red filled triangles (joined by a line of short dashes).

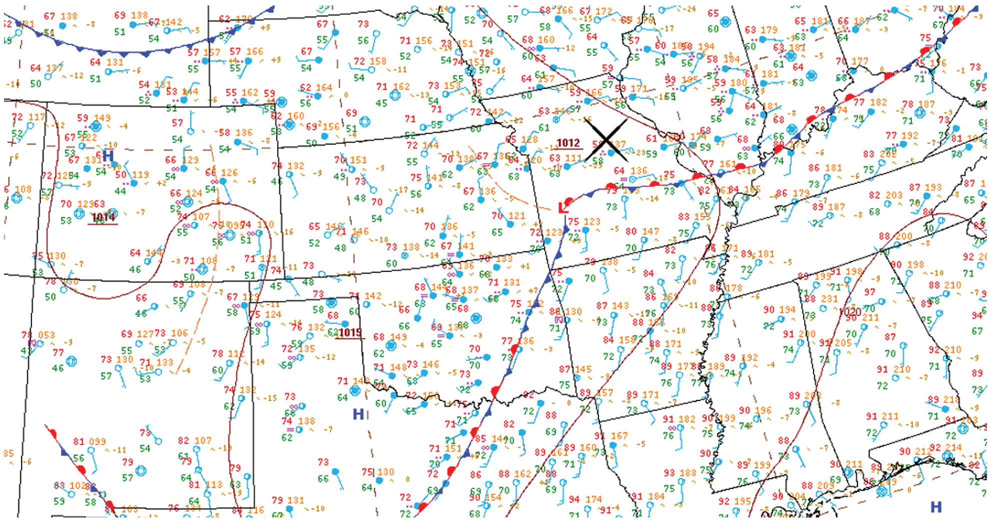

Figure 4. Standard surface analysis for the central United States valid at 1800 UTC 8 July 2015 from the United States Weather Service Weather Prediction Center. Bold 'X' marks the location of Columbia, MO.

3.2. Case 2: 7 July 2015

For the 2015 case, each of the three flights examined also occurred north of a surface quasi-stationary frontal boundary (Figure 4). Sounding balloons were released at 1448 UTC (Figure 5(a)), 1737 UTC (Figure 5(b)) and 2035 UTC (Figure 5(c)) on 8 July 2015, from the University of Missouri South Farm, just south of Columbia, MO, USA.

The first flight (Figure 5(a)) clearly identified elevated CAPE (188 J kg^{-1}) for parcels initiated above the top of the inversion. Indeed, a steady light to moderate rain occurred during all the three flights, with embedded showers scattered about the region as verified by radar (not shown). Also, surface winds at 1448 UTC ranged from 5 to 9 knots, with no gustiness noted at the time. A comparison of the DCAPE at 84 J kg^{-1} to the DCIN at 140 J kg^{-1}, shows that the DCAPE < DCIN, thus suggesting an inability for the downdraft to penetrate all the way to the surface.

By 1737 UTC (Figure 5(b)), the elevated CAPE had grown to 281 J kg^{-1} and some drying aloft had allowed the DCAPE to grow to 150 J kg^{-1}, while the DCIN shrunk some to 107 J kg^{-1}. Embedded convection became more plentiful by this time, with several areas having radar returns of 40 dBz or more (not shown); higher rainfall rates (~6 mm h^{-1}) were observed at this time. Surface wind gusts began in the ensuing few hours, corroborated by the surface weather observations at the Columbia Regional Airport (KCOU), located ~11 km south-southeast of the radiosonde launch site. There, surface wind gust criteria were met briefly, and reached 22 knots at 1950 UTC. Wind data from the nearby surface station at Jefferson City, MO (KJEF; ~29 km south-southeast of the radiosonde launch site), were also examined and compared to the radar reflectivity (Figure 3(b)) from the University of Missouri radar, as the KJEF site experienced stronger radar reflectivities (centerline of lowest tilt at ~550 m

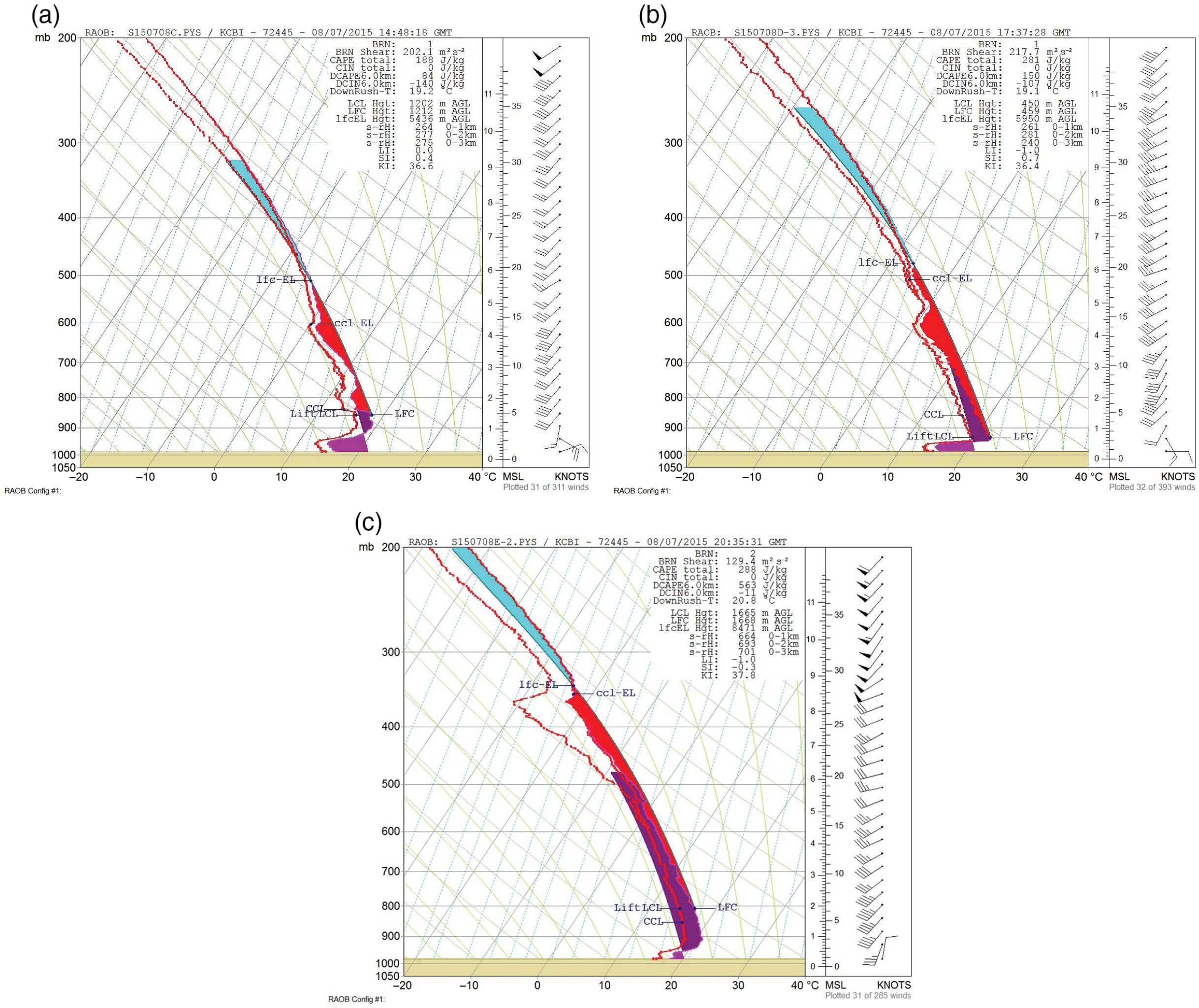

Figure 5. As in Figure 2, except for sounding analyses from Columbia, MO, flown on 8 July 2015, and valid at (a) 1448 UTC, (b) 1737 UTC and (c) 2035 UTC.

above ground level). Clearly, there are several periods that day with reflectivities in excess of 30 dBz, but the period with the strongest reflectivity values over KJEF also corresponds to the period of surface wind gusts.

The sounding at 2035 UTC (Figure 5(c)) largely conformed to a moist adiabatic profile, and while rain persisted, there were fewer radar-depicted convective cores (not shown). The elevated CAPE was essentially unchanged (288 J kg^{-1}), so the weak convective towers that were observed were no surprise. Meanwhile, the DCAPE had grown to 563 J kg^{-1}, while the DCIN shrunk to 11 J kg^{-1}. There is also an agricultural monitoring station at South Farm, immediately adjacent to the sounding launch site. For most of the day, wind speeds recorded by the station's anemometer (3-m exposure) did not stray above 7 knots; at 2137 UTC, 1 h after the 2035 UTC balloon launch, the day's peak gust, 16 knots, was recorded.

3.3. Previous work

The work of Horgan *et al.* (2007) provides additional soundings to test the utility of DCIN. Horgan *et al.* (2007) examined five cases of elevated convection that produced convectively induced severe weather reports (mostly winds) at the surface. Each of these cases had a significant inversion that was based at the surface. The soundings from each case in their work were acquired, and DCAPE (DCIN) values were calculated for each one, with the results shown in Table 1. Clearly, DCAPE is much larger than DCIN in most of the Horgan *et al.* (2007) cases, except for Case 2. However, they did mention the possibility that the profile above the inversion may have been contaminated by existing convection. No other of their cases generated similar concerns.

4. Summary

The DCIN is examined as a means to help confirm whether convection is elevated or surface-based. Although, Nowotarski *et al.* (2011) contend that convection is only truly elevated when no surface-based CAPE is present, having such a sounding where the DCIN is larger than DCAPE should prohibit surface-based parcels from becoming part of the deeper convective circulation via continuity.

Table 1. Dates, Times (UTC), DCAPE and DCIN values (units of $J\,kg^{-1}$) for Case 1 (Clinton, MO) and Case 2 (Columbia, MO) collected by the authors for this work as well as the individual values from the five severe cases from the Horgan *et al.* (2007) study.

Case	Date	Time	DCAPE	DCIN
1	2 April 2014	**0534**	**160**	**163**
1	2 April 2014	**0753**	**314**	**119**
1	2 April 2014	**0937**	**266**	**125**
2	8 July 2015	**1448**	**84**	**140**
2	8 July 2015	**1737**	**150**	**107**
2	8 July 2015	**2035**	**563**	**11**
HSC1	20 November 1986	**1200**	**713**	**9**
HSC2	28 December 1983	**1200**	**7**	**541**
HSC3	1 February 1983	**1200**	**538**	**1**
HSC4	3 November 1983	**1200**	**555**	**0**
HSC5	31 July 1986	**1200**	**1226**	**0**

The two accompanying case studies corroborate this idea, bolstered further by the coincidence of non-severe surface wind gusts accompanying the strongest radar reflectivities and (presumably) the most vigorous downdrafts. In addition, we reexamined five cases from a recent study of severe weather (high wind) reports from elevated convection (Horgan *et al.*, 2007), and found soundings that tended to have small to non-existent DCIN values and much greater DCAPE values. Indeed four of the five severe weather cases featured the condition where DCIN $\ll$ DCAPE, and parcels aloft were able to penetrate to the subinversion layer. The DCIN and comparisons to its DCAPE appear to be viable diagnostics for aiding in the assessment of elevated convection. As DCIN becomes less than DCAPE, downdraft penetration will become more likely; where DCIN is greater than DCAPE, downdraft penetration will become less likely and elevated convection will become more preferred.

While the idea proposed is supported by the observations, these results could be more quantitative. Given the limited number of soundings, it is difficult, at present, to determine a *precise* threshold of DCIN/DCAPE for the onset of surface downdraft winds. Additional factors, including the downdraft speed, wind profile above the inversion and the height of the level of neutral buoyancy, will need to be examined. Ongoing work on this topic seeks to (1) build a larger observational dataset (via simultaneous radar, rawinsonde and tall tower measurements) of similar cases and (2) use numerical modeling experiments, to better understand the aforementioned processes that influence downdraft behavior.

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